Effects of Urban Storm Water Runoff on the Natural Environment, Effects of the Natural Environment upon People, and Greenspace Solutions to Remediate Potential Flooding in the Proctor Creek Watershed:

The Case of Proctor Creek Watershed, and the Designation of a Partial Greenway Multipurpose Corridor Between Midtown and Downtown

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Abstract: The case for undertaking a bicycle trail project must illustrate a number of justifications in an era where motor vehicles are the default mode of transit. In recent years, non-motorized transit has become at once trendy in its current representation among urban planning issues, and of crucial importance in its need to be brought to the forefront of public attention; the rise of numerous health crises associated with a sedentary lifestyle has brought about a resurgence in bicycling and other methods of active commuting. In Atlanta, the congestion of travelers on any given day has created a concurrent crisis of transit, leading some to forego the vehicle in favor of the bicycle, and for many to reconsider whether it is worth their while to use a vehicle to navigate the city. A second concurrent issue, that of urban storm runoff, is extensive in its reach. Cities are characterized by grey spaces, with extensive areas of imperviousness, and Atlanta, while very rich in greenspaces as well, is no exception. Runoff entering the watershed has the potential to cause a number of hydrological and ecological disruptions, in addition to exacerbating any flood areas that may emerge in cities that experience generous rainfall and inundation events from local rivers. With the reclamation of abandoned paved parcels, and conversion to semi-permeable greenway materials, the total area of impermeability in Atlanta may be decreased. Here, I propose via scenario analyses of environmental overlay, transit patterns, and socioeconomic regressions the value of a mixed-use, multi-material greenway forming a belt around the northwest quadrant of Atlanta's inner perimeter.

SECTION I: Literature Review Regarding the Relationship Between the City and the Floodplain

Considered among the most outlandish of concepts in the early industrial age of the United States, Olmstead and Vaux's Central Park of New York City was a sight that seemed pleasantly out of place within the city's factory district in 1859. The sprawling expanse of greenspace is today viewed as exemplary among the many and varied manifestations of the green infrastructure movement throughout North American cities over the past 157 years, and a cornerstone innovation in greenspace planning and land conservation. In 2007, PlaNYC was released by the office of Mayor Michael Bloomberg; this plan initiated the city's moves against the effects of urban climate change. It has been written that there are both "yin" and "yang" elements to intelligent planning (Drummond), and the balance of these elements is more relevant in the face of modern climate change than ever before. In particular, PlaNYC addressed such factors as the city's outdated and failing storm and sewer infrastructure, and went into detail regarding the reconstruction of such systems. Sewer testing and reconstruction may be viewed as a remedial element that is "yang" in its nature; the work of remodeling the city's sewers to rectify current issues is a human interference-based ("yang") solution to one impact of climate change, and also a partially corporate affair; the city contracts a number of companies to perform the labor of sewer flow testing, observation of storm and flood events, soil and gas analyses, and the demolition and rebuilding of failing wall structures. This creates a situation rife with opportunities for economic growth, and promotes a "helpful development" mindset. Conversely, the greenbelt and parks pattern that has been employed both historically and in modern community planning is an example of "yin" solutions to the impacts of industrialization, specifically the combating of impervious surface coverage.

Parks systems are built upon a reasoning that is almost entirely non-interference based, with the preservation of natural turf, tree and water forms as the keystone concept. Within Atlanta, the preservation-minded movement of safeguarding the Proctor Creek watershed is an example of "yin" planning; additionally, the city's expansive parks system, and the newly-minted Atlanta BeltLine tying this system together as a cohesive network, are shows of the city's commitment to land conservation in the form of green infrastructure. Watersheds are natural landforms that lie at the heart of many communities and metropolitan areas, and impervious surfaces that characterize the urban landscape are the manmade enemy of the watershed. Given such factors as the sizable degradation of aquatic systems due to immense rainwater runoff over impervious cover in the developed world, (and the accompanying alteration of physical and biological relationships between riverine and floodplain environments, in addition to the hazard of polluted water loads being fed into natural waterways), the externalities of urban development with regard to environmental and public health merits rectification through watershed preservation. This is in part achieved through the preservation of greenspaces, which naturally serve to absorb storm runoff.

The past three decades have yielded a wealth of research on the topic of the geological watershed, with a direct relationship between impervious cover area and whole floodplain system disruption being the main trend, and human-driven remediation being called upon to slow this trend. My capstone project is based upon the following literary examination of urban storm runoff, and also upon the previously discussed concept of greenspaces and greenways as a potential remediation measure. In the phases of completion following this review, I employed GIS analyses of greenspaces as potential runoff remediation within the Midtown and Downtown neighborhoods of Atlanta. I was able to ultimately produce a suite of maps exhibiting the Proctor

Creek watershed in times of flooding, the geology of Atlanta's bedrock structure and vulnerability to nonpoint source chemical erosion, and a potential greenway connector of midtown Atlanta to serve human needs, while also combating the deleterious effects of urban runoff. Section I of my capstone paper here covers the history of the urban environment, the hydrology and ecology of the riverine aquatic system, the physics of moving streams, and the alteration of natural systems by urban storm water runoff. Additionally, this section covers the occurrence of pollutants in water, systems for urban biofiltration, and a few ways in which the built environment may be outfitted with treatment and utilization technologies for storm water.

Impervious surface is any material used as ground cover that halts water permeating the soil (Arnold and Gibbons, 1996). Shingles and other roofing materials make up a major percentage of impervious cover, likewise ground pavement for roads and building lots (Arnold and Gibbons, 1996). Impervious surfaces also exist naturally in the form of compacted clay soils, which possess the smallest grain size of all sediments, and also the highest reading on the psi scale; because of the tightness with which these clay sediments are arranged during their formation, the rate at which they absorb water is much lower than that of sandy soils or gravel. Outcroppings of bedrock also constitute impervious surfaces, as mineral composite matrices are impermeable to water. Since the end of human nomadism, and the rise of intransient farm-based society during the Neolithic Revolution, people have built dwellings sheltered from the elements by rain-resistant roofs. Additionally, road systems for travel and trade were arguably the most important element of the built environment in our progress as a social species. Pavement is, of course, a recent phenomenon; according to a census report dating back to pre-industrial times, ninety-three percent of American roads were unpaved in 1904 (Southworth and Ben-Joseph, 1995, as cited by Arnold and Gibbons, 1996). Additionally, the rise of the interstate highway system in the 1950s served not only to inherently increase the amount of paved roadways, but also to increase the amount of paved building lots for residential properties; the interstate made easier the spread of the American suburb, and the commuter lifestyle (Arnold and Gibbons, 1996).

With the rise of suburbia, the increase in transit by privately owned automobiles, and the industrialization of the American city came a rise in the alteration of raw land into plots for the built environment. Environmentally-minded individuals have for decades advised us regarding the effects of urban growth on the natural environment. Specifically, hydrologists and geologists have kept watch for the ways in which runoff from paved roadways and roofing buildings affect the hydrologic cycle, the processes by which water moves through the troposphere (lower atmosphere), hydrosphere (oceanic environs), lithosphere (terrestrial environs), and biosphere (plants, animals, and detritus). An 18% percent increase in urban impervious cover has the ability to generate an 80% volume increase in yearly average runoff (Bhaduri et al., 2000), and Harbor (1994) documented an eleven-fold increase in storm water runoff due to impervious cover with the conversion of woodland to high-density residential and commercial uses. Changes in the rates and pathways of water flow due to urban runoff eventually lead to deleterious short-term effects such as downstream flooding of riverine environments, and long-term damage such as stream degradation (erosion of the shoreline) and a decrease in supply of groundwater (an increase in urban runoff has the ability to produce a decrease in groundwater recharge of eleven to one hundred percent) (Bhaduri et al., 2000). Additionally, land conversion produces such statistics as heavy metal pollutant increases of greater than 50% and farm nutrient contaminant increases of 15% (due to runoff from agricultural areas) (Bhaduri et al., 2000). Furthermore, Booth et al. (2004) documented a decrease in the benthic index of biological integrity in the wake of land conversion in the Puget Sound lowlands of western Washington; freshwater macroinvertebrates as vastly varied as mollusks, annelids, trematodes, and arthropods were shown to drop in species diversity following alteration of hydrologic regimes. Ground zero for the hydrologic regime alteration produced by urban runoff is the watershed, also known as a catchment area, a drainage divide, or a drainage basin. The watershed is a fluvial area, located in the vicinity of a riverine environment; usually funnel shaped due to the conical slope of the land comprising the origins of riverine tributaries, this landform collects rainwater, snow, and all other direct precipitation or runoff. The watershed is environmentally crucial because it feeds collected precipitation and runoff, including runoff from the built environment due to impervious cover, into natural bodies of freshwater via riverine tributaries.

Included in the broad category of natural bodies of water are river valleys. Arguably the most important landform in the history of human civilization, nearly all prominent civilizations throughout primitive global history were built in the vicinity of riverine aquatic systems; this trend continues today, with a great number of cities built around rivers and their tributaries, and in many ways reliant upon them. Riverine aquatic systems are defined as mainstream rivers, their tributaries, and the sedimentary environments encompassed within; additionally, floodplain environments and watersheds may be included in this definition. Floodplains are the lands surrounding a river's mainstream and tributaries, receiving floodwater from the river's swell during the spring, and also from stream runoff following such events as damming or breakage in the river bed (Sedell and Froggatt, 1984). In turn, the floodplains are responsible for the return of detritus, the decomposition products of organic matter, to the river after flooding events wash stream runoff into and back out of the floodplain (Sedell and Froggatt, 1984). In this way, the riverine and floodplain environments are intertwined, with each environment influencing the other equally. Rivers of all sizes are effected by the floodplain, from lowland streams to the largest rivers at the 9th to 12th order (Sedell and Froggatt, 1984); Vannote et al. (1980, as cited by Sedell and Froggatt, 1984) found the primary biological and chemical roles of floodplains to be that of organic particulate decomposition at low tide, and the return of decomposition products following inundation; greater autochthonous (floodplain-sourced) carbon input and lower allochthonous tributary (non-floodplain-sourced) carbon input to 7th through 9th order streams has been exhibited, reinforcing the point of floodplain influence on the largest of rivers. Welcomme (1979, as cited by Sedell and Froggatt, 1984) posed that floodplain fishery productivity exhibits a positive correlation with spatial and temporal extent of flooding; such a correlation bears implications not only for the entwinement of the floodplains and larger streams within a riverine aquatic system, but also for the entwinement of riverine ecology with the economy. Furthermore, Wissmar et al. (1980, as cited by Sedell and Froggatt, 1984) posed that terrestrially-sourced organics and inorganics are responsible for the microbial activity of the Amazon and its tributaries and floodplain lakes.

Chemical and biological upshots of river-floodplain relationship breakdown have been demonstrated in laboratory studies, with lab trials mimicking the effects of natural inundation cycles on sediment beds by using rounds of saturation and drying. In soil samples designated as reverse controls, or groups in which a change from the normal hydrologic regime is most predicted to occur, complete desiccation is induced. One such laboratory study revealed that flooded and then partially dried floodplain-sourced sediments were highly reactive with any available phosphorus and nitrogen, mimicking the natural pulse in the nitrogen cycle following inundation (Baldwin and Mitchell, 2000). There exists the possibility of chronically reduced availability of both of the above elements with the disruption of existing hydrologic regimes within aquatic systems, and the reduced availability of nitrogen and phosphorus may be exacerbated by the uptake of minerals by root structures of remaining plant species in desiccated areas (Baldwin and Mitchell, 2000). Additionally, the anaerobic bacteria responsible for the fixation of nitrogen in soil were shown to completely die out in desiccated soils; in the absence of these anaerobes, denitrification and also soil affinity for phosphorus comes to a halt, and phosphorus no longer exhibits affinity for iron minerals present in soil sediments (Baldwin and Mitchell, 2000). In undisrupted floodplain hydrologic regimes, rewetting of desiccated soils has been shown to induce a new influx of available nitrogen and phosphorus, and a new boom in nitrification by bacterial processes (Baldwin and Mitchell, 2000). It has been observed, furthermore, that the inundation of floodplain soils results in increased availability of not only nitrogen and phosphorus, but also carbon; this is due to the freeing of these minerals from both the sediments themselves and also the leaf litter covering the grounds (Baldwin and Mitchell, 2000). An increase in productivity in heterotrophic biotic components of this particular ecosystem is the final result of inundation (Baldwin and Mitchell, 2000). This signals a new beginning to the cycle, in which increased productivity of heterotrophs must in turn lead to anoxia in floodplain sediments, as oxygen is needed in order for aerobes to carry out their life processes. Anaerobic processes will likewise experience a boom after this point; as the soils become anoxic, an increase can be observed in the processes of denitrification and phosphorus release (Baldwin and Mitchell, 2000); this speaks to the importance of the natural cycles of flooding and draining that are most threatened by urbanization processes such as river jam interference and floodplain drainage.

There exists an indirect relationship between the sensitivity of an aquatic system and the area impervious cover within a watershed needed to cause degradation to that system. That is, the more sensitive the hydrological balance of a given aquatic system, the lower the number of square feet covered by impervious material needed to cross the threshold into stream degradation (Booth and Jackson, 1997). Effective imperviousness is used as a measure of the urban watershed covered by impervious surfaces, and this measure is abbreviated to EI; in studies of effective imperviousness, impervious surfaces are defined as any synthetic surface impermeable to water (Walsh et al., 2005). Where catchment areas meeting streams are not covered with impervious surfaces, rainfall undergoes natural filtration of pollutants, is absorbed by the soil, and eventually serves to replenish groundwater; no such course of action can be followed over watersheds covered by impervious surfaces. Investigations of the Seattle metropolitan area began in 1997, with lowland streams data from Western Washington state demonstrating riverine aquatic system degradation in the vicinity of areas with ten percent or greater impervious cover; by that point, such a percentage impervious cover was characteristic of the average urban expanse, and the resulting erosional degradation of riverine environments became a proxy for measuring the amount of rainwater lost by the common urban system (Booth and Jackson, 1997). Additionally, Booth and Jackson postulated that impervious cover could be used effectively as a proxy for urbanization and its environmental effects.

Conversely, Booth followed up his 1997 study with another in 2004, in which he and others posit that impervious cover is less than ideal as a surrogate for degradation of the stream; according to the authors, it is the more direct route of examining the alteration of hydrologic regimes that should consulted in this case (Booth et al, 2004). Because changes in hydrologic dimensions such as the pathways, the rate of flow, the average depth, and the shape of the river basin are the direct mechanisms for stream degradation, authors point away from impervious cover readings when attempting to obtain accurate information regarding river health in a given area (Booth et al, 2004). However, erosional damage to riverine systems as the result of widespread impervious cover in the vicinity of urbanized areas has been documented by Walsh et al. (2005) in their study of catchment areas in Melbourne, Australia. Impervious surfaces cover many watersheds in Melbourne, leading to a greater quantity of pollutant laden rainfall being fed into natural bodies of water than in catchment areas devoid of such impervious surfaces (Walsh et al., 2005). When a large enough quantity of rainfall reaches a stream as a result of impervious surface-covered catchment areas being directly connected to the stream bed, the stream will experience a significant measure of disturbance due to turbulence from the physics of water being fed into it, and chemical disturbance from pollutants (Walsh et al., 2005). Runoff effects of urban storm water are numerous, and include not only the previously discussed erosion and flooding disruption, but also disruption of species succession in primary producers (plants), dissolved oxygen decrease and temperature rise in natural bodies of water, eutrophication in natural bodies of water from spikes in the nutrients nitrogen and phosphorus, and toxicity in natural bodies of water from solid and industrial metallic wastes (Marsalek and Chocat, 2002). Impervious cover has been used as an environmental indicator for decades, but another issue confronting scientists and planners alike is the health of our freshwater resources. Local level water resource protection has become complicated by the recognition of non-point source pollutant contamination via water runoff. Because so widespread, the Environmental Protection Agency has recognized this type of pollution as America’s topmost water quality issue since 1994 (Arnold and Gibbons, 1996). The sources of pollution are urban impervious surfaces, where contaminants are washed off by rainwater and then either leached into soils and groundwater, or transported to nearby waterways via impervious cover extension to the watershed (Arnold and Gibbons, 1996). Such environmental hazards have historically not been given much thought, as the primary concern of planners when considering the drainage of rainwater has more often than not been the clearing off of rainwater from city streets and sidewalks for safety reasons. The prevention of flooding, property damage, and vehicular accidents have been foremost on the planning agenda until modern day consideration of chemical pollutants and the deleterious long term effects of their diffusion on the quality of our water resources and the stability of our natural environment (Arnold and Gibbons, 1996).

When pollutant discharge trends from urban runoff are studied mathematically to create curves for modeling future pollutant loads, discharge during different rainfall events are compared using dimensionless mass-volume curves, which indicate the distribution of pollutant mass versus volume of water discharged from urban sewer systems (Bertrand-Krajewski et al., 1998). Using direct testing of urban sewers across France, Bertrand-Krajewski et al. (1998) observed 197 rainfall events in 12 separate and combined sewer systems. A separate sewer system is one in which storm water is designated its own drainpipe, separate from a second drainpipe used for wastewater (Mannina and Viviani, 2009). Both storm water and treated waste water are shunted out of the city via these drainpipes, with waste water making its way to a treatment facility and collected storm water going directly to the watershed (Mannina and Viviani, 2009). In a combined sewer system, a single shared drainpipe is used for both storm water and waste water, and both are brought to the waste treatment facility; any untreated overflow is shunted to the watershed (Mannina and Viviani, 2009). Bertrand-Krajewski and others observed a "first flush phenomenon"; results showed 80% of total pollutant mass transported in the first 74% total volume for 50% of rainfall events in separate sewer systems, and in the first 79% total volume for 50% of rainfall events in combined sewer systems (Bertrand-Krajewski et al., 1998). Characteristics of mass-volume curves are determined by the pollutant being measured, the site being observed, the nature of the rainfall event, and lastly by the functioning (separate or combined) of the sewer system (Bertrand-Krajewski et al., 1998); mass-volume curves are excellent for illustrating the inherent variability of the first flush phenomenon and also the importance of immediate action if the desired result is pollutant concentration reduction in storm water discharge, as every rainfall is doing damage within the first few minutes of discharge.

Biological retention is posed as a way to combat the spread of pollutants from urban storm water runoff into natural water systems. Bioretention is performed by porous soil, hardwood, mulch, and live plant species; these materials remove heavy metals and nutrients from urban storm water (Davis et al., 2001). Using pilot-scale lab systems, Davis et al. (2001) performed a laboratory controlled study in which synthetic urban storm water was filtered through layered retention materials (plants matter, soils, mulch). Authors found a greater than 90% reduction in all metals with bioretention, and 60 to 80% reduction in nitrogen, phosphorus, and ammonium (Davis et al., 2001). Little nitrate was removed; on the contrary, nitrate production increased (Davis et al., 2001). It became known after this point that the traditional method of plant and soil based bioretention does not filter out nitrate. Kim et al. (2003) sought to follow the work of Davis et al. (2001) and complete this task of bioretention using microbial denitrification in a lab-based study. Lab conditions mimicked an anoxic watershed undergoing continued submergence by rainwater. This study was divided into four phases, with the first two phases showing newspaper to be the best electron donor for denitrification, phase three demonstrating viability of the system after dormant periods of thirty days and eighty-four days (indicating that intermittent loading of storm water could be effectively handled by this bioretention system), and phase four demonstrating up to eighty percent of nitrate removed (Kim et al., 2003). Additionally, watershed drainage has been posed as a potential solution to the multiple issues of urban runoff; upon observing drainage systems utilizing retrofitted drain pipes, Walsh et al. (2005) documented an overall increase in chlorophyll-a density (a proxy for primary productivity by plants and plant-like protists) across watersheds in Melbourne, in addition to an increase in the number of invertebrate families represented.

Roofs constitute a large percentage of impervious cover; the high storm water runoff from impervious cover is now being mitigated by green roofs, or the growing of vegetation over the entire surface of a roof to recover lost green space; VanWoert et al. (2005) performed two studies on these “green rooftops”. This study was divided into two trials to test two conditions: vegetation and roof slope. The first trial consisted of three rooftop treatment groups; the first was commercial roofing made of the standard gravel ballast, the second was a green roof with no vegetation yet in place, and the third was a standard green roof complete with vegetation (VanWoert et al., 2005). The second trial consisted of correlative analysis of roof slope, (with examples of 2% slope and 6.5% slope) and green roof media depth (2.5 cm, 4 cm, and 6 cm) against storm water retention (VanWoert et al., 2005). Results showed gravel roofing to retain the lowest percentage of water (48.7%) and vegetated green roofing to retain the highest percentage (82.8%). Roofs with a slope of 2% and a media depth of 4 cm were shown to have the highest percentage of water retention (87%), although the general trend is that of decreased runoff with a minimal slope and increasing media depth (VanWoert et al., 2005).

Conscientious planning offers a solution to the issues caused by urban runoff. Smart growth is a buzz word in today’s world; part of its definition is comprised of planning a city’s layout and land uses based upon the knowledge of geographically specific environmental impacts. Now that planners have access to the wealth of geographically specific statistics provided by GIS, there has evolved a new movement of smart growth planning based upon technical methods. Planning research uses land use GIS models when predicting trends in the building of future cities. In one study, Conway and Lathrop (2003) focused on four parameters to create four build-out scenarios for the future of the Barnegat Bay watershed in New Jersey; these parameters were the regulations in place at the time of the study, down zoning, the protection of a buffer around wetlands, and the protection of parcels allotted as open space. In all four build-out scenarios, the management of water was the highest priority; models predicted that, regardless of the parameter to which consideration was given, urban areas would experience a demand for potable water that surpassed supply, a further breakdown of river-floodplain relationships (and accompanying chemobiological disruption and fragmentation of wildlife habitats), and severely decreased quality of what water is available for human consumption (Conway and Lathrop, 2003). Likewise, Tang et al. (2005) conducted analysis of the Muskegon River watershed in Michigan using a land use change model and an environmental impact model. Results showed that the Muskegon River watershed will be subject to further nonpoint source pollution and physical damages from urban runoff in future build-out scenarios if solutions are not reached. According to these models, increasing urbanization along the east coast of Lake Michigan will increase the volume of delivery of urban runoff to the watershed, in addition to the volume of delivery of metallic and nonmetallic pollutants and hydrocarbons (oils and greases) from runoff (Tang et al., 2005).

The collection and storage of storm water has been posed in conjunction with watershed drainage (Walsh et al., 2005) and bioremediation (Davis et al., 2001 and Kim et al., 2003) as interference-based solutions to the impacts of urban runoff; that is, the next generation of planners may be tasked with the initiative of intercepting and cleansing rainwater to meet the needs of city inhabitants, and also to divert harmful runoff from the watershed and beyond by both the above “yang” methods, and also through the “yin” of our parks systems.

In modern times, there are many tools that are within our grasp to remedy the harmful effects of urban runoff. From Walsh and others’ account of the collection of all runoff in the urban watershed (2005), Sedell and Froggatt’s account of the ecology of the river-floodplain environment (1984), and Baldwin and Mitchell’s account of the living environment we do not necessarily see every day (2000), to Bertrand-Krajewski and others’ account of the presence of pollutant concentrations in urban runoff of which we are all too aware, the effects of urban runoff in our cities is well-documented. The use of results from research that has been performed in the past is the first step toward designing better systems for the future. Today, more than ever, planners are taking heed of models that analyze past occurrences to predict future trends. Whereas in the past, the stability of the environment was often the last thing to be considered when planning and designing the urban built environment, the present time is a turning point, where we see the tangible effects of past planning, and where we have access to almost limitless amounts of information to be used in building stronger, more sustainable cities.

SECTION II: Data Acquisition, building a Simple Toolbox and Tool Script, and the Use of Python to Perform Multiple Data Clips

Project shapefiles were taken from many sources, and encompassed relatively extensive areas such as Fulton County, the immediate ten counties of the Atlanta Regional Commission, and the state of Georgia. I wrote this tool to clip all of my preliminary data to the extent of the Proctor Creek Watershed and to the City of Atlanta as needed following the instructions outlined in lecture for Class 8 *(GIS Capstone, Catalogued CP 6950)*. My first task was to author a .py file containing the code for running the tool named “Clip” from within the Arc Toolbox named “Analysis Tools”. Below is a transcript of the script I wrote.

Script Text:

```
# set Python default directory
import os
os.chdir('c:/capstone/shapefiles'
import arcpy

# sets default workspace
arcpy.env.workspace = "c:/capstone/shapefiles"

# Uses Clip Analysis tool on Networkable Path line data from Atlanta Regional Commision.
Clips performed using Atlanta's boundary, taken from City of Atlanta.
arcpy.Clip_analysis("ARCMajorRoads.shp", "ATLBoundary.shp",
"Foote_ATLMajorRoads.shp")
arcpy.Clip_analysis("ARCRivers.shp", "ATLBoundary.shp", "Foote_ATLRivers.shp")
arcpy.Clip_analysis("ARCStreets.shp", "ATLBoundary.shp", "Foote_ATLStreets.shp")
```

 # Uses Clip Analysis tool on Land Cover polygon data from Atlanta Regional Commision. Clips performed using Atlanta's boundary, taken from City of Atlanta.

arcpy.Clip_analysis("ARCGreenspace.shp", "ATLBoundary.shp", "Foote_ATLGreenspace.shp")

 # Uses Clip Analysis tool on Land Cover polygon data from Fulton County. Clips performed using Proctor Creek watershed's boundary, taken from USGS NHD.

arcpy.Clip_analysis("FLTTaxParcels.shp", "PRCTWatershed.shp", "Foote_PRCTTaxParcels.shp")

arcpy.Clip_analysis("FLTTransitZones.shp", "PRCTWatershed.shp", "Foote_PRCTTransitZones.shp")

 # Uses Clip Analysis tool on Land Cover polygon data from Perez, Italiano, Leitz, and Foote (2016). Clips performed using Proctor Creek watershed's boundary, taken from USGS NHD.

arcpy.Clip_analysis("FLTFloodzones.shp", "PRCTWatershed.shp", "Foote_PRCTFloodzones.shp")

 # Uses Clip Analysis tool on Emergency Station point data from Fulton County that will eventually serve as facility point input for location-allocation assessment. Clips performed using Atlanta's boundary, taken from City of Atlanta.

arcpy.Clip_analysis("FLTEmergencyStations.shp", "ATLBoundary.shp", "Foote_ATLEmergencyStations.shp")

 # Uses Clip Analysis tool on Geologic Formation polygon data from the state of Georgia. Clips performed using Atlanta's boundary, taken from City of Atlanta.

arcpy.Clip_analysis("GAGeology.shp", "ATLBoundary.shp", "Foote_ATLGeology.shp")

 # Adds an exit message to the tool

arcpy.AddMessage("Now, view the map document entitled ClipByScriptTool.mxd; it is the introductory map to Foote's Capstone Project.")

Upon completion of this script and designating its pathway directory within my completed project folder, it was time to assign this script as a tool to a new toolbox. To do this, I began by right-clicking upon “My Toolboxes”, underneath the icon for “Toolboxes” within the

Catalogue window in ArcMap. I selected “New Toolbox” (Note: User beware, “New Python Toolbox” is not the correct option). Naming the new toolbox “Foote_CapstoneToolbox”, my next task was to right-click upon the new item and select “Add Script”. From here, I was able to designate the pathway that led to the script I had written as part of my capstone project folder.

The tool was a success, and clipped all of my shapefiles to the areas I’d specified. It was by this method that I was able to create my first map, shown below in Figure 1 of this section. A preliminary overview of my study area, the layers of this map are as follows:

- The city of Atlanta is displayed, with street networks visible in light blue and major roads visible in light purple.
- The Atlanta Beltline’s intended extent is pictured in seafoam green.
- Proctor Creek Watershed is shown with transit zone divisions in rose.
- Rivers are shown in dark blue, while vector flood zone data taken from FEMA is shown in golden orange.
- Shown in red is a second floodplain polygon, which was created as part of a flood project for Transportation GIS by Perez, Italiano, Leitz, and Foote (2016)

Interestingly, this map can also serve as a demonstration of my clip script as a tool to fix broken links. By establishing a sub-folder within my project folder known as “Shapefiles”, I was able to store my original shapefiles and delete those that resulted from running the clip tool (“shown with the prefix “Foote” for easy identification). When the user opens the map document entitled “ClipByScriptTool.mxd”, almost all of the pathways in the Table of Contents will appear with broken pathways. The simple fix is to close the broken map, start a new instance of ArcMap, and run my tool script; this will create the data and hence, call the data properly so that the user can view the map. Lastly, I encoded an exit message to appear in the results box upon completion of running my tool. It is transcribed below:

"Now, view the map document entitled ClipByScriptTool.mxd; it is the introductory map to Foote's Capstone Project."

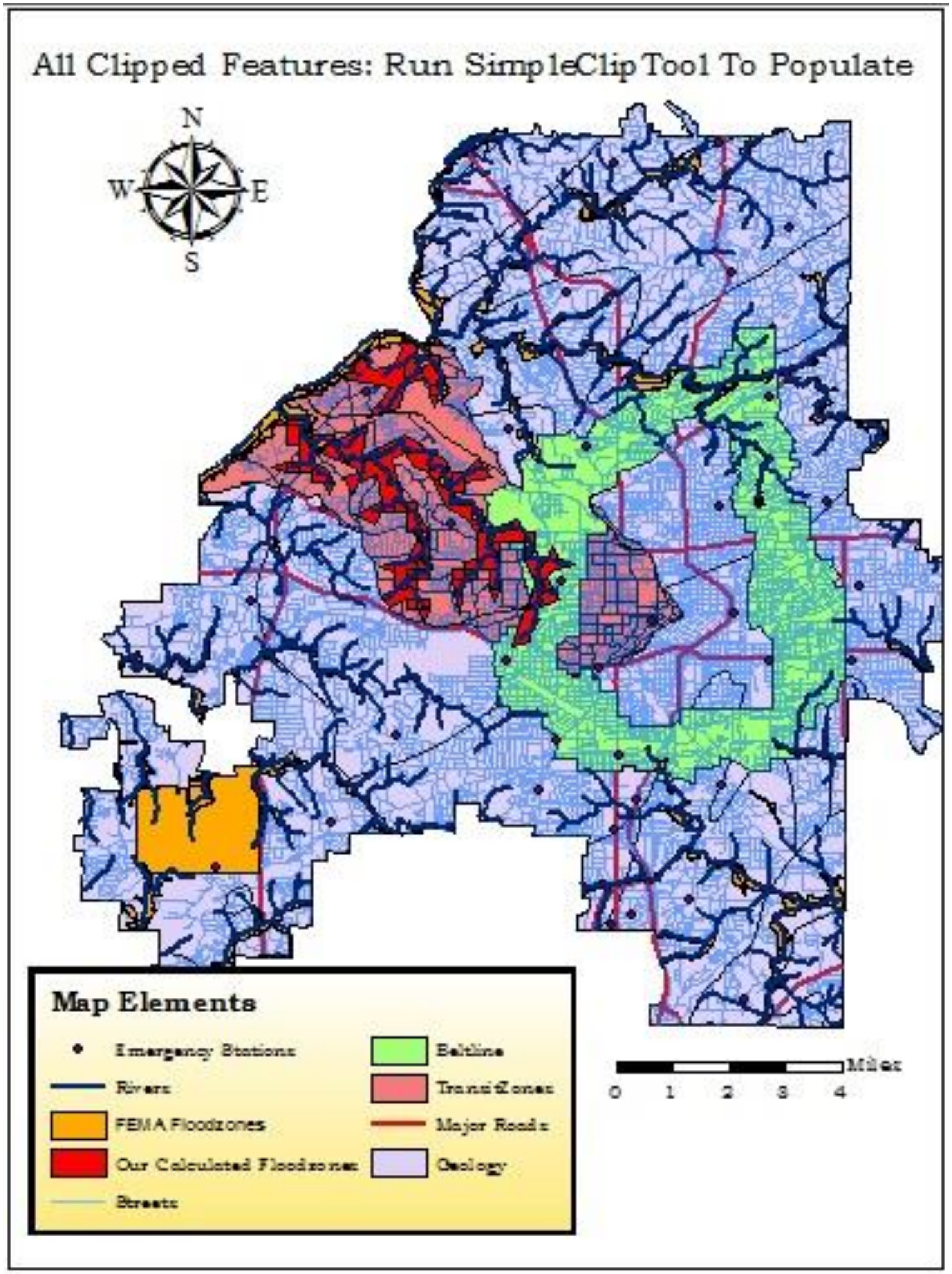

Figure 2.1: Overview map; run SimpleClipTool to populate.

SECTION III: A Raster Analysis for Flood Events, and a Transit Model for Emergency Flood Evacuation of Urban Residents

My first task in building the analysis of a flood event in the Proctor Creek watershed was to reacquaint myself with raster data I'd helped to create this past spring as part of a Transportation GIS project with classmates Amy Perez, Anne Italiano, and Chelsea Leitz (*Transportation GIS, Catalogued CP 6542*). One goal of this project was to determine areas prone to flooding based upon watershed raster analysis. Using the spatial analyst tools, we built stream networks for the purpose of predicting these areas of complete inundation. The first step in our analysis was that of acquiring a DEM model of Fulton County from USGS, and then applying the fill tool to the DEM; this filled sinks in the raster data to remove imperfections and minimize errors. Our next step was to apply the flow direction tool to the DEM; this tool determined the direction of flow from each cell within our elevation raster. Next, we applied the flow accumulation tool. This tool uses cellular flow direction to determine the amount of water received by each cell; the higher the value returned by this tool, the more likely it is that the cell is part of a stream network. Moving forward, we calculated the threshold of the stream. Using the raster calculator, we used 5000 as the threshold; this value translates to 1.7 square miles using this formula:

$$985.ft * 98.5\ ft = 30m*30$$

From the Stream Link tool, we were able to create a stream network based on the flow direction previously generated. The next steps included the tools Stream Order, Stream to Feature, and Flow Length. Each of these tools relies on the flow direction of water into and out of a cell in order to piece together the streams in proper order. The finishing task was that of loading raster data from USGS containing information on basins, area wide watersheds, and point-based watersheds.

ArcHydro is a specialized subset of tools within the Spatial Analyst toolbox. Unlike the standard Hydrology toolbox, ArcHydro allows clients to carry out both hydrologic and hydraulic modeling. The first step in our hydrologic model involved reconditioning our DEM of Fulton County. This step adjusted the surface elevation of the DEM to be consistent with the Fulton streams vector coverage. Then, the reconditioned DEM was filled. The final output DEM was later used for our reclassification process, which yielded a final shapefile in the form of a vector polygon of all total inundation floodplains in Fulton County.

It was now time to perform my location allocation analysis for the purpose of demonstrating the severely decreased vehicular accessibility of hospitals (and lesser "emergency stations") within the Proctor Creek watershed in times of total inundation. To begin this model, I built a network dataset from Fulton County street data taken from the Fulton County website. Distance/length was designated as the sole attribute, and miles as the unit of measurement. Fulton County households were represented by parcel and zone data in my analysis, with data taken from the Fulton County website. Emergency medical service centers are represented by hospital and emergency station data, which was taken from the Atlanta Regional Commission website and clipped from the ARC's ten-county reach to the extent of Fulton County. FEMA 100-year flood data was acknowledged in preliminary non-inundation analyses, and loaded as a polygon barrier in my first three models. The flood data created by Perez et al. (2016) was used as a polygon barrier in my fourth analysis depicting a total area inundation event.

To create inputs for an initial Fulton County scale location-allocation, my first step was to designate zone centroids in order to convert polygon data to point data. This was done via the feature to point tool. Hospital data was loaded as facility points and zone centroids were loaded as demand points. At 1,297 centroids, loading took about two hours. FEMA 100-year flood data was loaded as a polygon barrier. The final map from this location-allocation depicts a large-scale, moderate-precision view of the Fulton County by neighborhood, and the Fulton County hospitals that would meet the demands of these neighborhoods with the least impedance in the event of little to no inundation following rain events in Fulton County. The results are displayed in this section's Figure 1.

The second task was to repeat this measure for zones within the Proctor Creek watershed. Following this, it was possible to create a location-allocation model indicative of facility reachability in times of little inundation from Proctor Creek following a rainfall event; zone data is good for scenarios where most individuals are choosing the same facility as their neighbors without care given to road flooding. There are 156 transit zone centroids designated for the Proctor Creek watershed, in addition to 22,245 tax parcel centroids designated for this area. The map from this location-allocation depicts a small-scale, moderate-precision view of the Proctor Creek watershed by neighborhood, and the Atlanta city hospitals that would meet the demands of these neighborhoods with the least impedance in the event of very little or no flooding following a rain event in the watershed. This map is displayed below in Figure 2.

When transit zone centroid data is replaced by tax parcel centroid data within an otherwise identical location-allocation model, the map output depicts a small-scale, high-precision view of the Proctor Creek watershed by household, and the Atlanta city hospitals that would meet the demands of these households with the least impedance in the event of little to no inundation following a flood event in Proctor Creek. As mentioned above, the centroid data for this trial numbered demand 22,245 points, and needed to be left overnight to load properly. The resulting map is displayed below in Figure 3.

To finish, I created a fourth map, this time depicting an event of widespread inundation and total road submergence. This final location-allocation analysis designates the Atlanta hospitals that would meet the demands of the Proctor Creek watershed by household in such a flooding event. All inputs remained the same except for that of the polygon barriers; in this case, the floodplain shapefile by Perez et al. (2016) was used in substitution for FEMA 100-year flood data. The final map from this location-allocation depicts a small-scale, high-precision view of the Proctor Creek watershed by household, and the Atlanta city hospitals that would meet the demands of these households with the least impedance in the event of widespread inundation and total road submergence following a flood event in Proctor Creek. This map is displayed below in Figure 4.

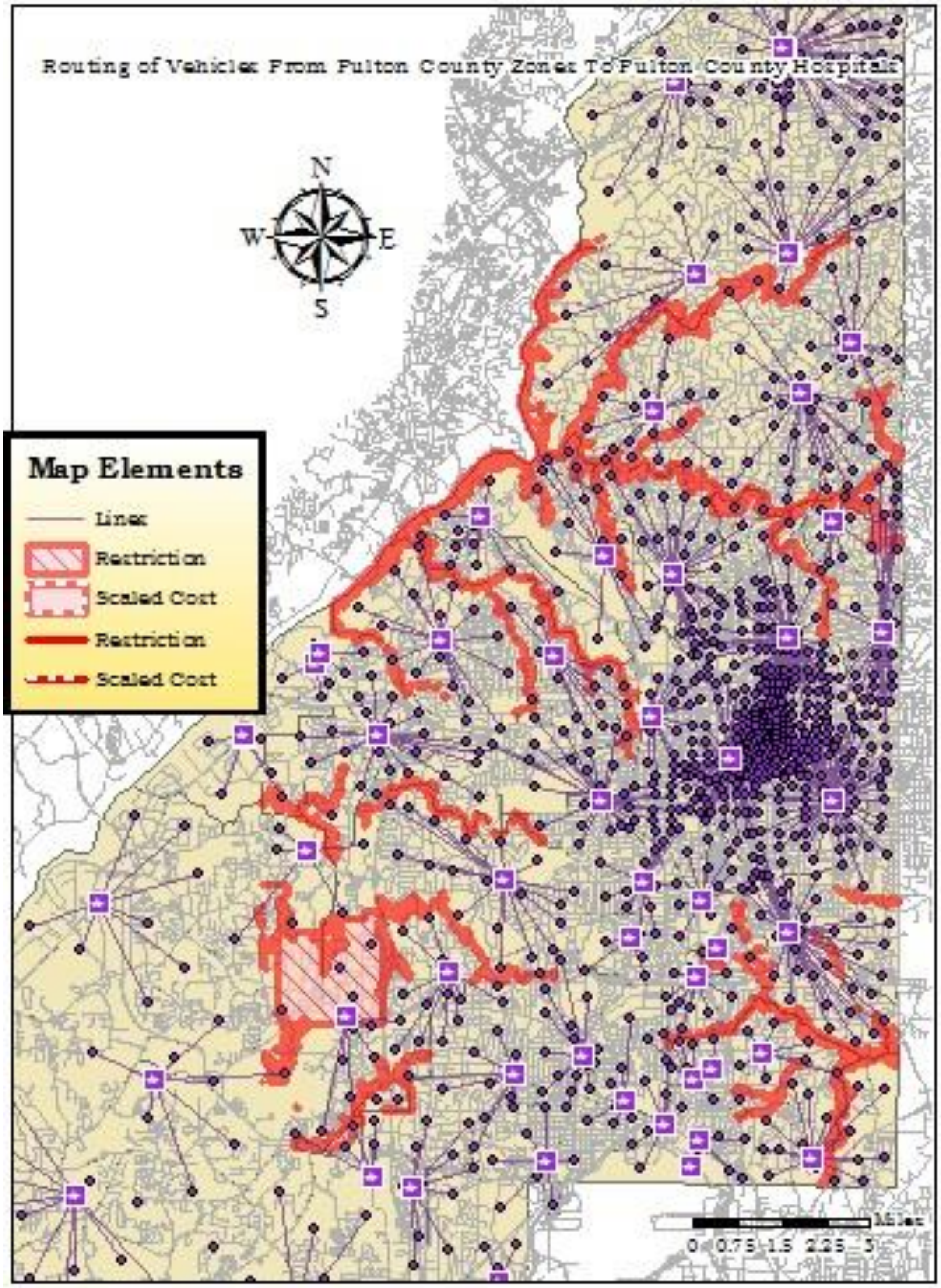

Figure 3.1: Large-scale, moderate-precision representation of vehicular access to hospitals and emergency stations in times of little to no flooding in Fulton County following a rainfall event, with polygon barriers being loaded from FEMA floodplain data.

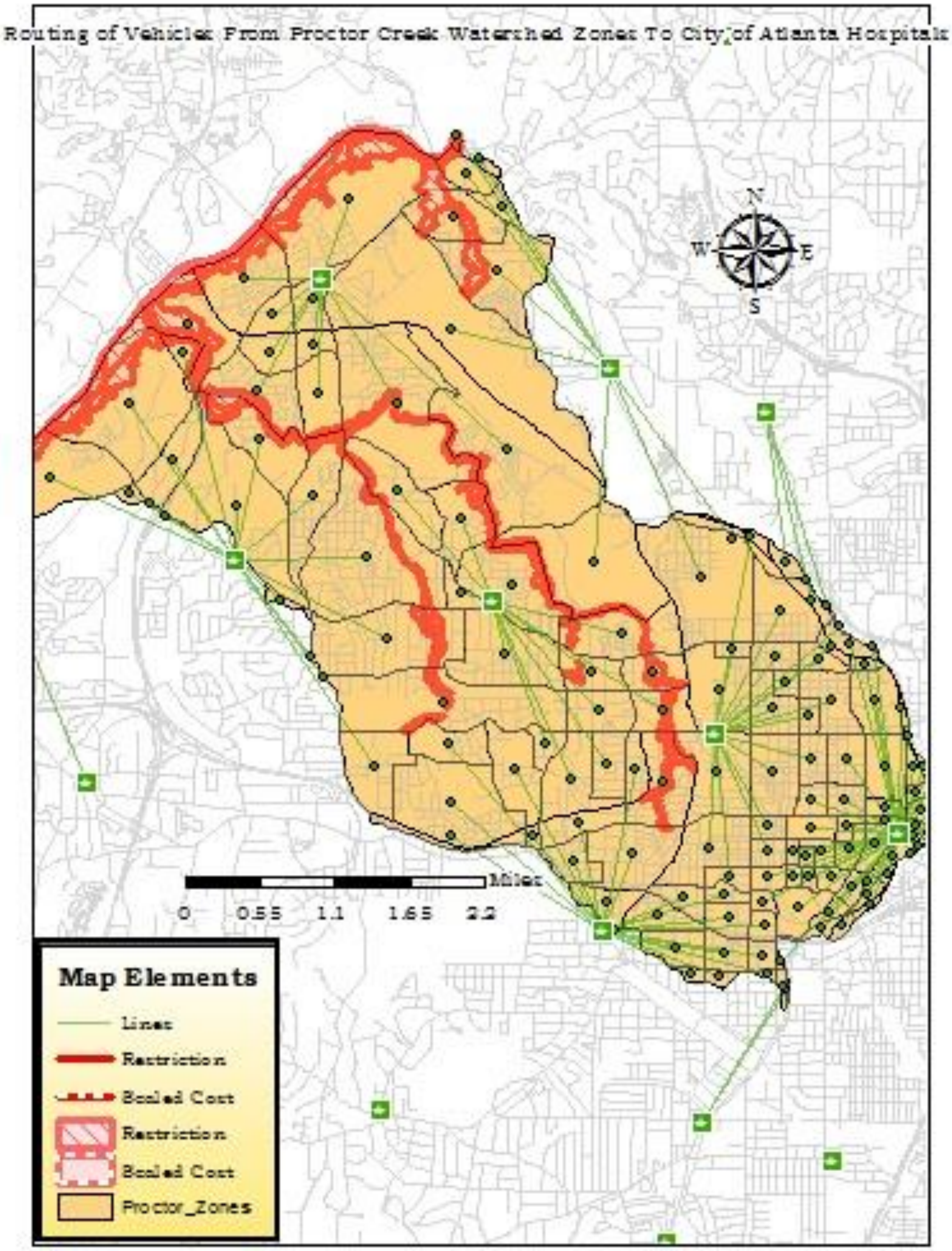

Figure 3.2: Small-scale, moderate-precision representation of vehicular access to hospitals and emergency stations in times of little to no flooding in Fulton County following a rainfall event, with polygon barriers being loaded from FEMA floodplain data.

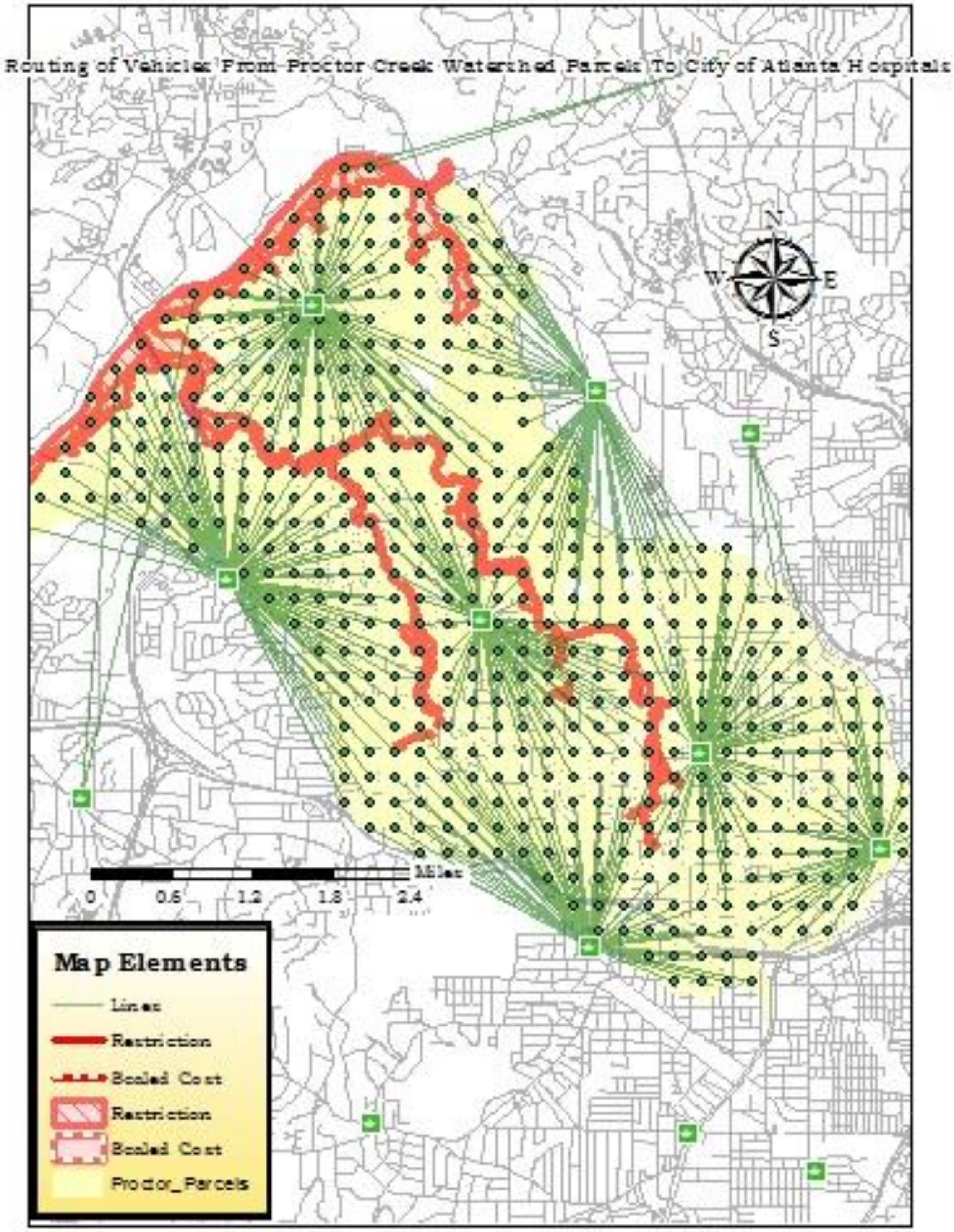

Figure 3.3: Small-scale, high-precision representation of vehicular access to hospitals and emergency stations in times of little to no flooding in Fulton County following a rainfall event, with polygon barriers being loaded from FEMA floodplain data.

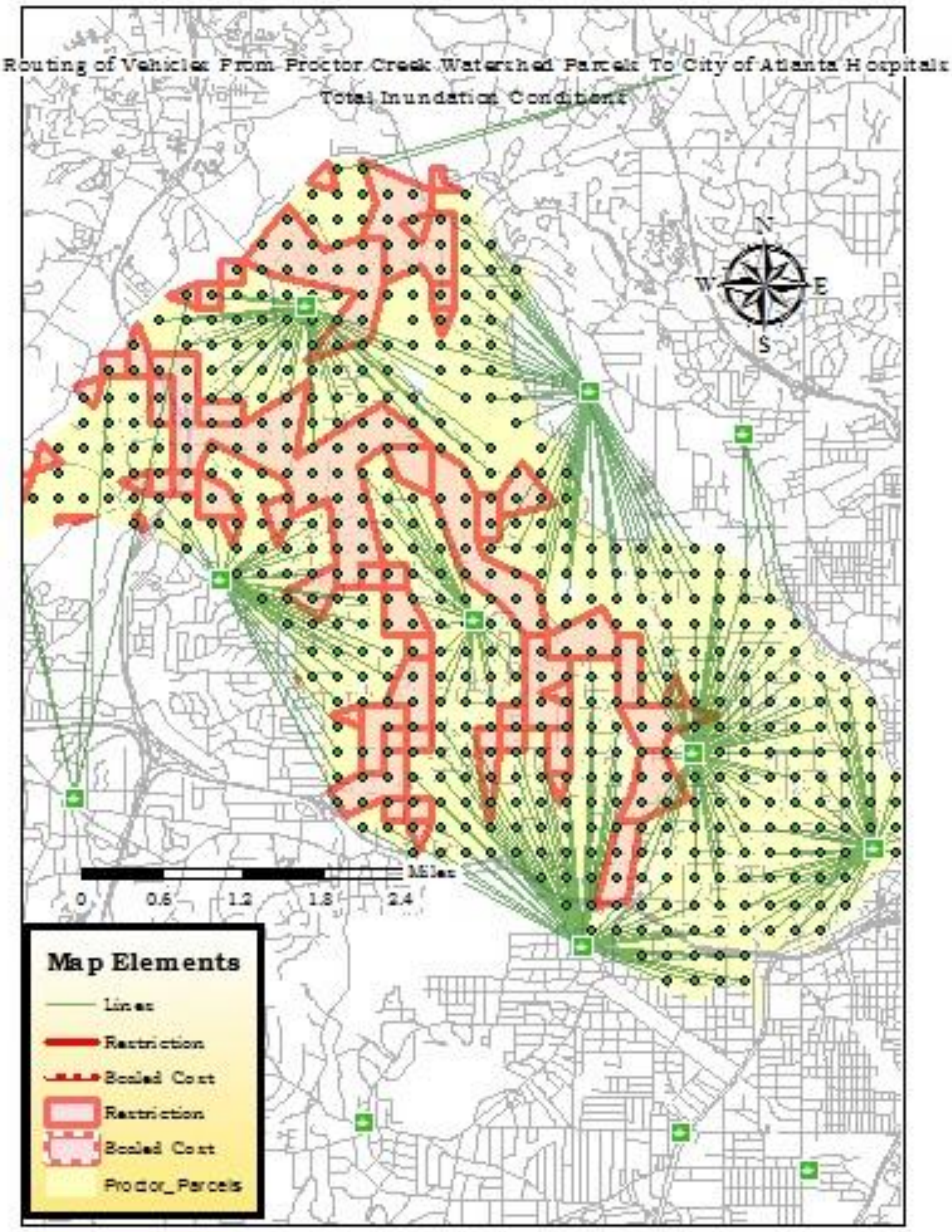

Figure 3.4: Small-scale, high-precision representation of vehicular access to hospitals and emergency stations in times of severe flooding in Fulton County following a rainfall event, with polygon barriers being loaded from the floodplain data of Perez et al., 2016.

From the preceding maps, we see that there are tracts of land in the southeastern reaches of the proctor creek watershed that have access to more than one hospital with ease during a flood event. These parcels comprise downtown Atlanta, and are my ideal destinations in the event of a flood evacuation scenario; due to their elevation, these parcels do not undergo road submergence in the event of floodplain drainage reaching as far as the polygon barriers I have added in my above transit models.

In times of floodplain expansion, inundation makes surrounding roads and properties dangerous to navigate; the properties and roads that exist within floodplains may not have vehicular access to hospitals, or even basic emergency stations. In the event of a flood evacuation order, persons within these areas will be called to leave their properties and migrate to the nearest parcels allowing vehicular access to emergency centers. When an evacuation order is made, residents ought to leave their area by any means necessary, although car is the preferred and city-recommended method of evacuation. Those without cars may be left carpooling out of the area with whomever is the local vehicle owner, or simply packing a few things and walking. Many choose to stay in their properties due to misunderstanding of situation's seriousness; if people in these areas wait too long in the event of a flood evacuation order, they are projected to need emergency response via other routes. Small watercraft such as motorized rafts or v-hull boats take a great deal of time to procure, and are used mainly in coastal and major riverine metropolitan zones (Jo et al., 2002). Other ways to evacuate include airlift by helicopter or small aircraft, which also take time in responding to a situation (Jo et al., 2002). To avoid the costliness associated with wait times for emergency response, and to enable the public in terms of timely evacuation in a flood emergency, the next question to be addressed is that of liberty of transit for urban citizens.

SECTION IV: The Westside Greenbelt Trail Becomes the Midtown-Downtown Connector

I postulate that bicycles may grow in popularity in the coming years in Atlanta. Bicycles are preservers of our environment in that individual and societal carbon footprints are reduced dramatically by their use. Also a driver of societal equity, the poorest members of society can arguably benefit the most from the convenience of owning a bicycle in such situations as simply getting to work every day, and also that of saving money that would otherwise be invested in car payments, gas purchase, and costly repairs.

Ownership of a bicycle may also play a role in providing a safe and fast exit from floodplain areas if an evacuation order is given far enough in advance of flood situations. Those who do not own vehicles will fare better in quickly leaving an area if commuting by bicycle, and have a better chance of reaching without incident the closest possible emergency stations and/or parcels with vehicular access to hospitals, (ideally, these people would be able to reach Downtown, located in the southeastern tracts of the Proctor Creek watershed as outlined in Section III). Shown in green in Figure 1 of this section, I designated the original parcels for this potential trail this past spring as part of a greenspace proposal for Land Conservation with Ben Sutton and Chirag Date (2016). The southeastern portion of this greenbelt trail makes a connection in Downtown Atlanta, providing direct access to the evacuation destination described in Section III.

I propose this greenway as a mixed material, multi-use corridor. As mentioned in Section I, impervious surfaces are still widely used in paving, with semi-permeable turf slowly gaining popularity. To propose this greenway as a completely paved corridor would, I believe, defeat its purpose as a contribution to the greenspaces of Atlanta; paved surfaces would ultimately embody an exacerbation to the runoff-induced disruptions of Proctor Creek's floodplain, propagating an already destructive pattern. To answer this challenge, I specifically propose this trail as a converted lot network, where parcels are converted to a network of soil and gravel. Candidate parcels would be vacant, or abandoned and unclaimed. Condemned parcels would ideally be rehabilitated, and then converted.

The completed greenway makes connections at its northeastern reaches at the Georgia Institute of Technology and Atlantic Station, two neighborhoods just beyond the watershed that are likewise notorious for flood events and road submersion during periods of heavy rainfall. I propose two BeltLine Crossing zones, to be outfitted with STOP signs, guard posts, and painted diagonal lines crossing the lanes of the BeltLine. These crossings are shown in blue in Figure 4.1, at locations adjacent to Washington Park and Ashby MARTA Station, and to Maddox Park and Bankhead MARTA Station. Additionally, I propose two bicycle bridges as part of the greenway's extent; one bridge would be constructed from steel beams to create an overpass for bicycles above the dangerous intersection of Northside Drive and Joseph Boone Boulevard. Providing a fantastic view of the newly-constructed Mercedes Benz Stadium, such a bicycle bridge might even become a famous spot for photographers and tourists. The bridge would segue seamlessly into the bicycle lanes that guide cyclists into the junction for downtown Atlanta. The second bicycle bridge I propose is a steel beam reconstruction of the stone bridge that once existed over the railways between Northside Drive and Marietta Street, behind the storehouses that today house such trendy businesses as Amelie's French Bakery. This bridge would serve as a connector between Donald Hollowell Boulevard and Marietta Street, provide cyclists with safe passage again over Northside Drive, and guide cyclists into the junction for Georgia Tech and Atlantic Station.

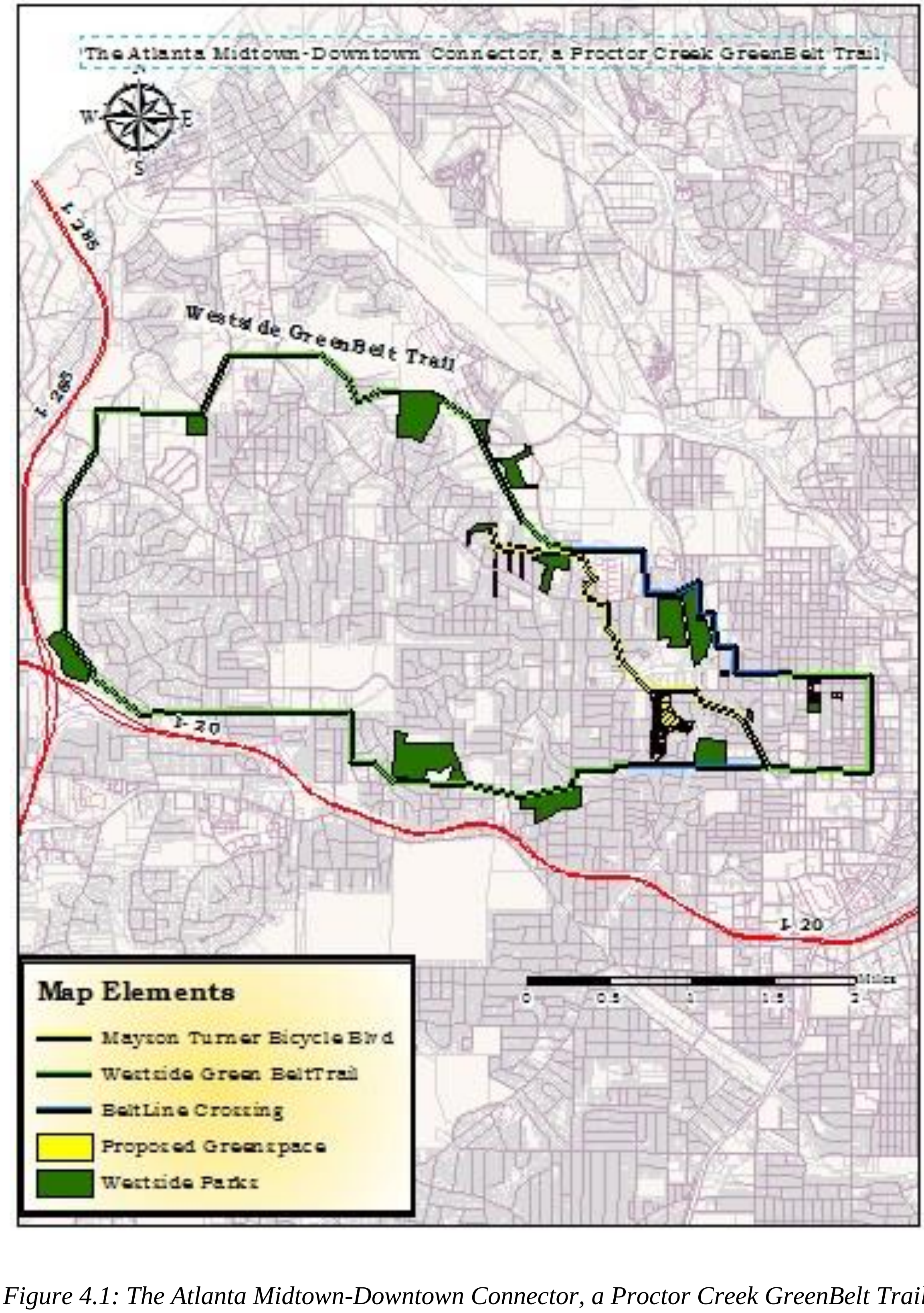

Figure 4.1: The Atlanta Midtown-Downtown Connector, a Proctor Creek GreenBelt Trail.

SECTION V: <u>Economics and the Geology-Based Principle of Conservation over High Rise Development in the Proctor Creek Watershed</u>

Conservation over conversion, or in our case high rise development in choice midtown and downtown parcels, is a difficult idea to sell for environmentalists and greenspace planners when confronted with the unstoppable bulldozers of “progress”. A great many of the parcels surrounding the Westside BeltLine and its projected path through the eastern border of the Proctor Creek watershed are either already designated as single family residential (and most already owned), or set aside for preservation as historical sites. It stands to reason that the BeltLine will bring with it the same increase in value of surrounding properties as seen in the development of the Eastside BeltLine; the parcels open for purchase on the Westside BeltLine are few and highly coveted by both those who would develop the land, and those who would conserve the land.

According to weighted overlay analysis performed by Dai et al. (2001), the three top factors in building construction are slope of a given parcel, lithology of its bedrock layer, and overall elevation. Dai et al. (2001) go on to specify build height categories; according to the nation’s current architectural standards, any building under 75 feet tall is a low rise building, and anything greater than or equal to 75 feet constitutes a high rise building. Building upon the principles set forth by Dai et al. (2001), I asserted that the lithology of load bearing rock layers may serve as a GIS-demonstrable proxy for informed decision making about where to develop and where to conserve. In this fifth section of my capstone paper, I cite principles of geology in examining the Proctor Creek watershed’s buildability.

Taking geological data from the State of Georgia via Fulton County, I was able to build a dataset within which all bedrock in Atlanta is digitized and described. The second, third, and fourth figures in this section are the maps that resulted from my categorizations of this geological data. The first figure in this section is a depiction of the Goldich Stability Series, a pyramid depicting the stability, or immunity to chemical weathering, exhibited by the most common minerals in the Earth's bedrock. According to this series, quartzes reside at the top of the pyramid as the strongest minerals; as the mineral most immune to chemical weathering, it stands to reason that soil leeching atop a bedrock of quartz minerals would not likely affect the bedrock's stability, or a building's safety. Map 5.1 depicts a pure granite bedrock on the Northside BeltLine, and granitic gneiss on the Southside; both of these rock types are rich in quartz, and present as good candidates for high rise development.

According to the Goldich Series, the second strongest mineral in terms of resistance to chemical weathering is muscovite mica. The southwest and southeast reaches of the Beltline are comprised of a bedrock layer of muscovite mica schist; these regions present as moderate candidates for high rise development, and most likely to be both efficient and favorable in terms of low rise development.

Located beneath quartzes and muscovite mica on the Goldich Stability Series is biotite mica. This mineral does not display the same high resistance to chemical weathering as muscovite mica and quartz; bedrock rich in biotite mica is more likely to be negatively affected by leeching from soils, particularly in a floodplain. The Proctor Creek watershed, in addition to the entirety of the northwest and northeast reaches of the BeltLine, exist upon a bed of biotite mica gneiss. In light of this, I produced my final two maps based upon the attributes of suitability, which I created for my third map, and actual suggested build height, which I created for my fourth map. With these maps considered, the Westside BelLine, and the Proctor Creek watershed in general, are not ideal places to build high rise structures.

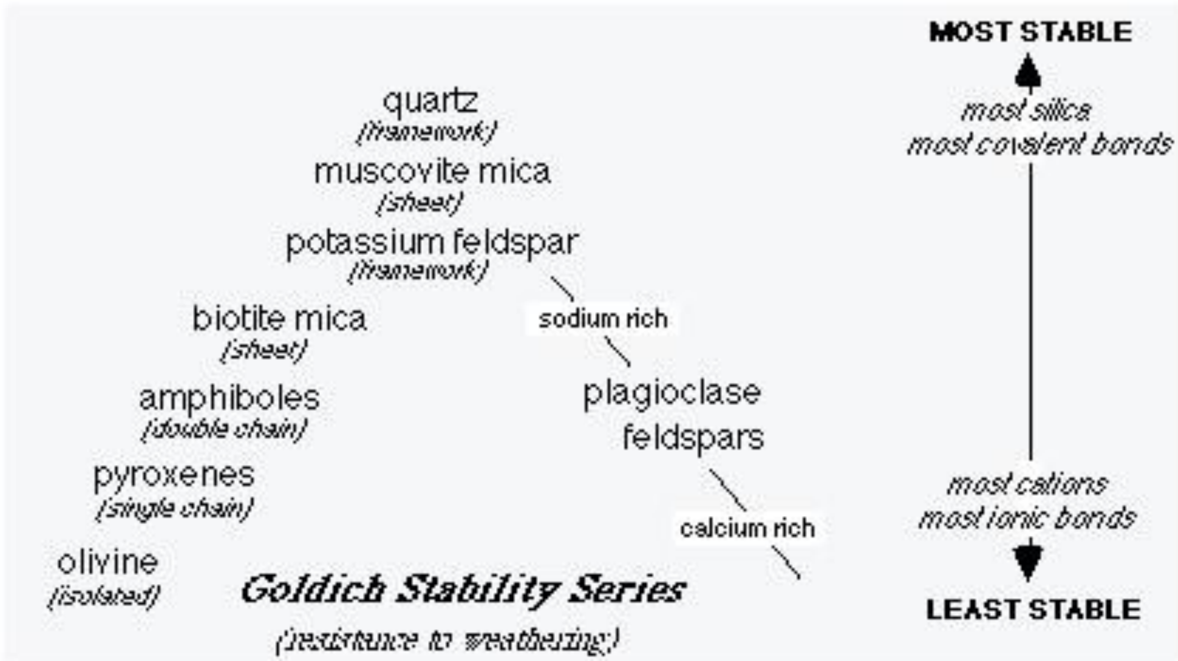

Figure 5.1 Goldich's Stability Series.

Photo credit: http://www.columbia.edu/~vjd1/weathering.htm

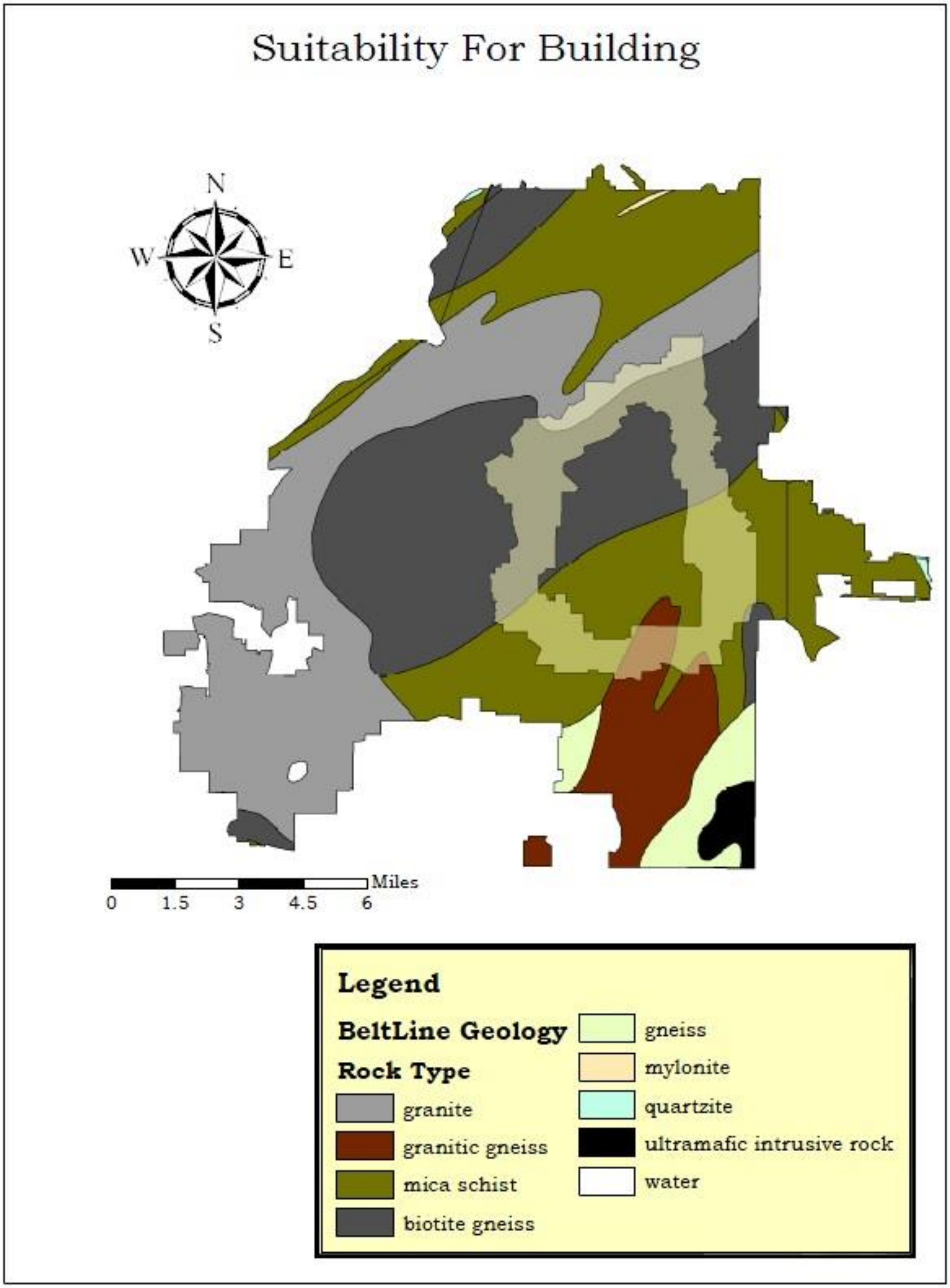

Figure 5.2: The bedrock types of Atlanta's BeltLine.

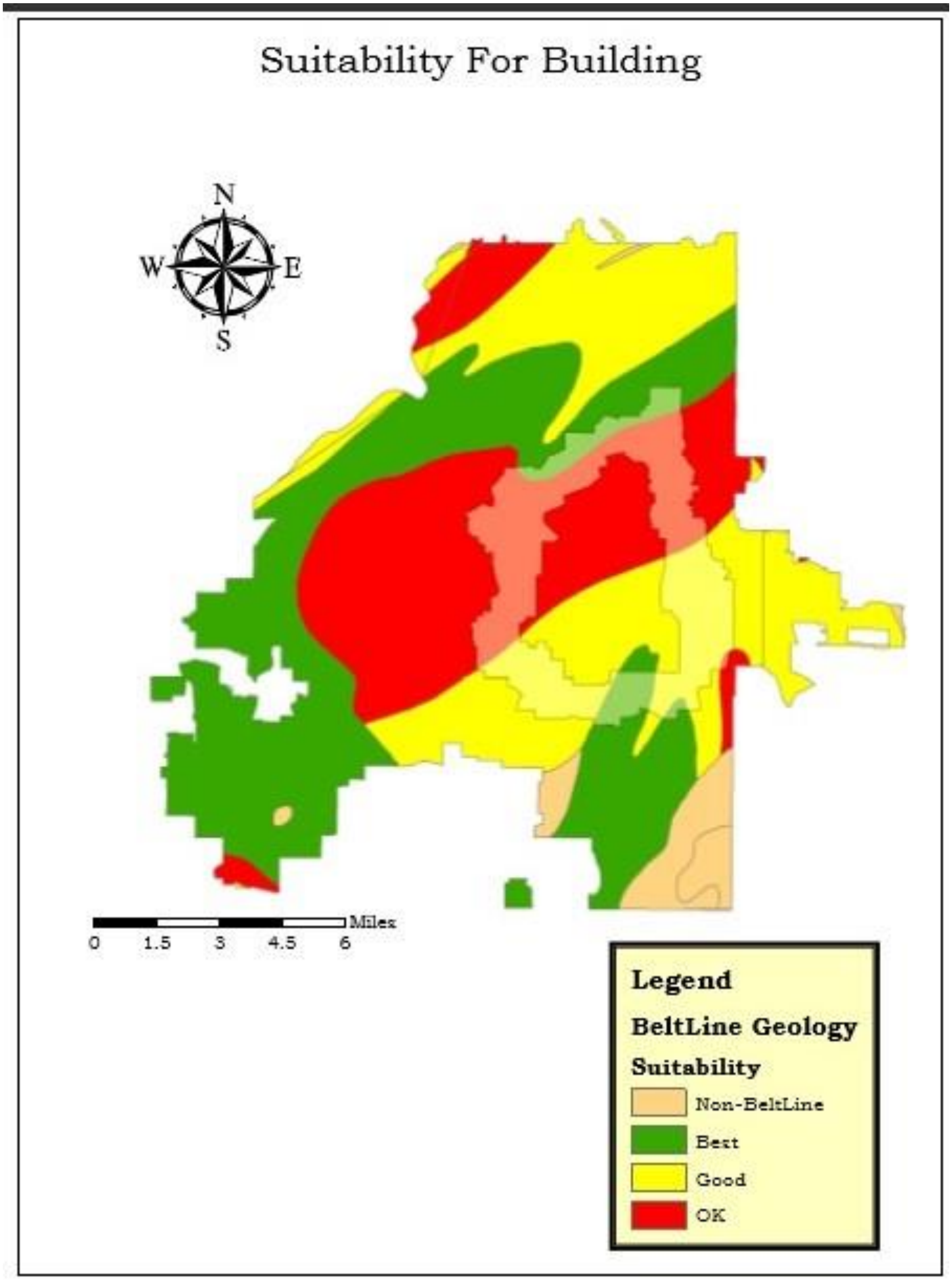

Figure 5.3: Suitability of Atlanta's Bedrock Types for Low and High Rise Development.

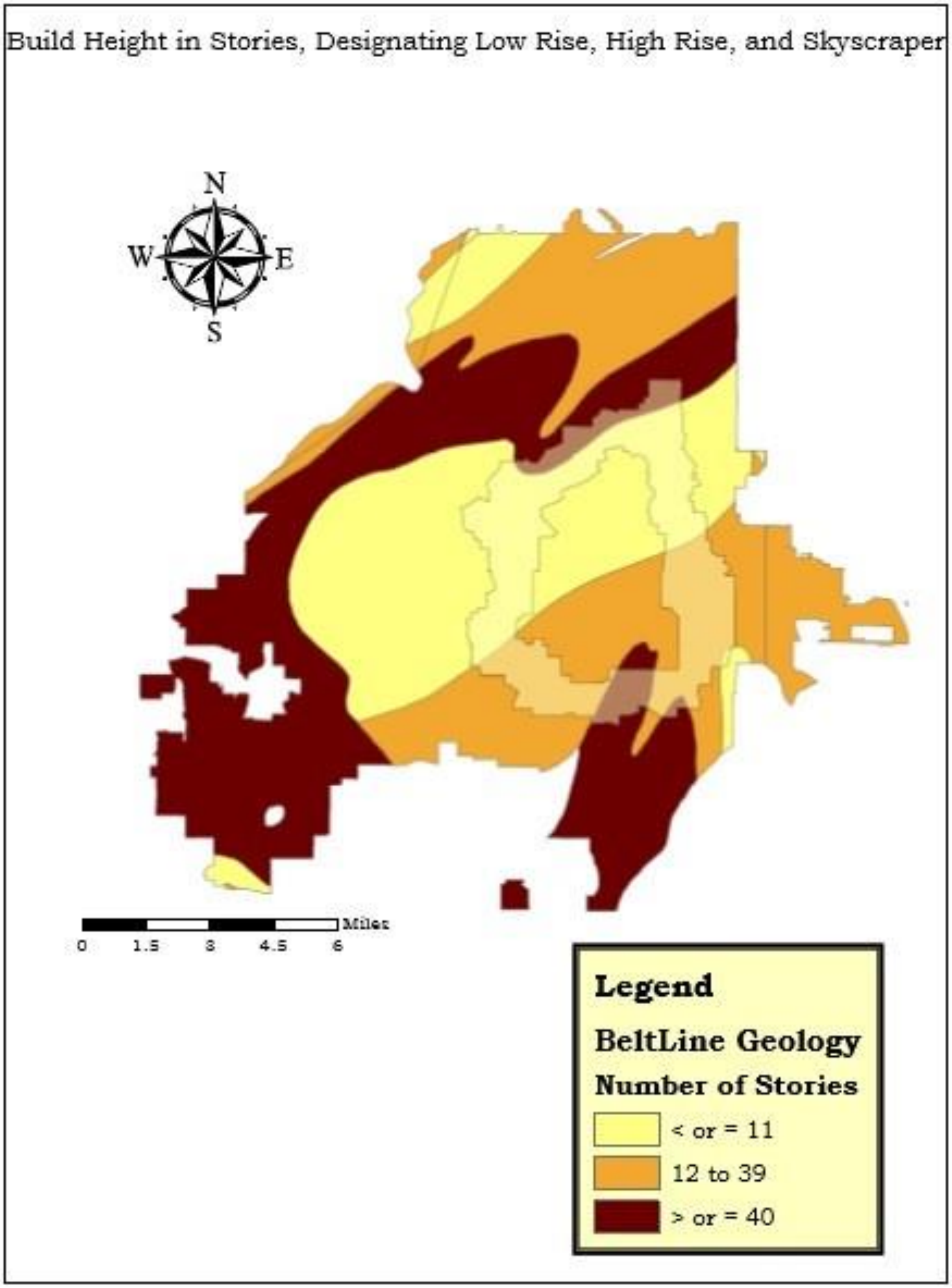

Figure 5.4: Buildability of Atlanta's BeltLine.

CONCLUSION:

In this capstone project, I posed the question “Can greenways save the world?”

There is no cure-all solution to the challenges faced by GIS and planning professionals involved in the work of land conservation and “smart growth”. Over this summer, I was able to grasp the final answer of “Perhaps Not” via work on this project.

While greenspace preservation and greenway designation cannot save the world, they can indeed help to protect the watershed, its biology, and its residents. Figure 6.1 is the final map in my capstone project, showing overlay of all of my main datasets. Issues of floodplain expansion (floodplain raster data shown as a lilac polygon barrier), inundation hazard (avoided using the green spider line routes of my location-allocation model), connectivity (via a Midtown-Downtown Connector), and chemical weathering (as evidenced by the presence of biotite schist in salmon red) are all addressed by the possibility of a mixed-material, multi-use partial or total greenbelt trail running throughout the Proctor Creek watershed, as suggested in this figure.

It has been a pleasure to bring this data together, and to present it as my capstone project. For further questions regarding this project, please feel free to reach me at my Georgia Tech email address, kefoote@gatech.edu, or at my personal email address, kefoote@utica.edu.

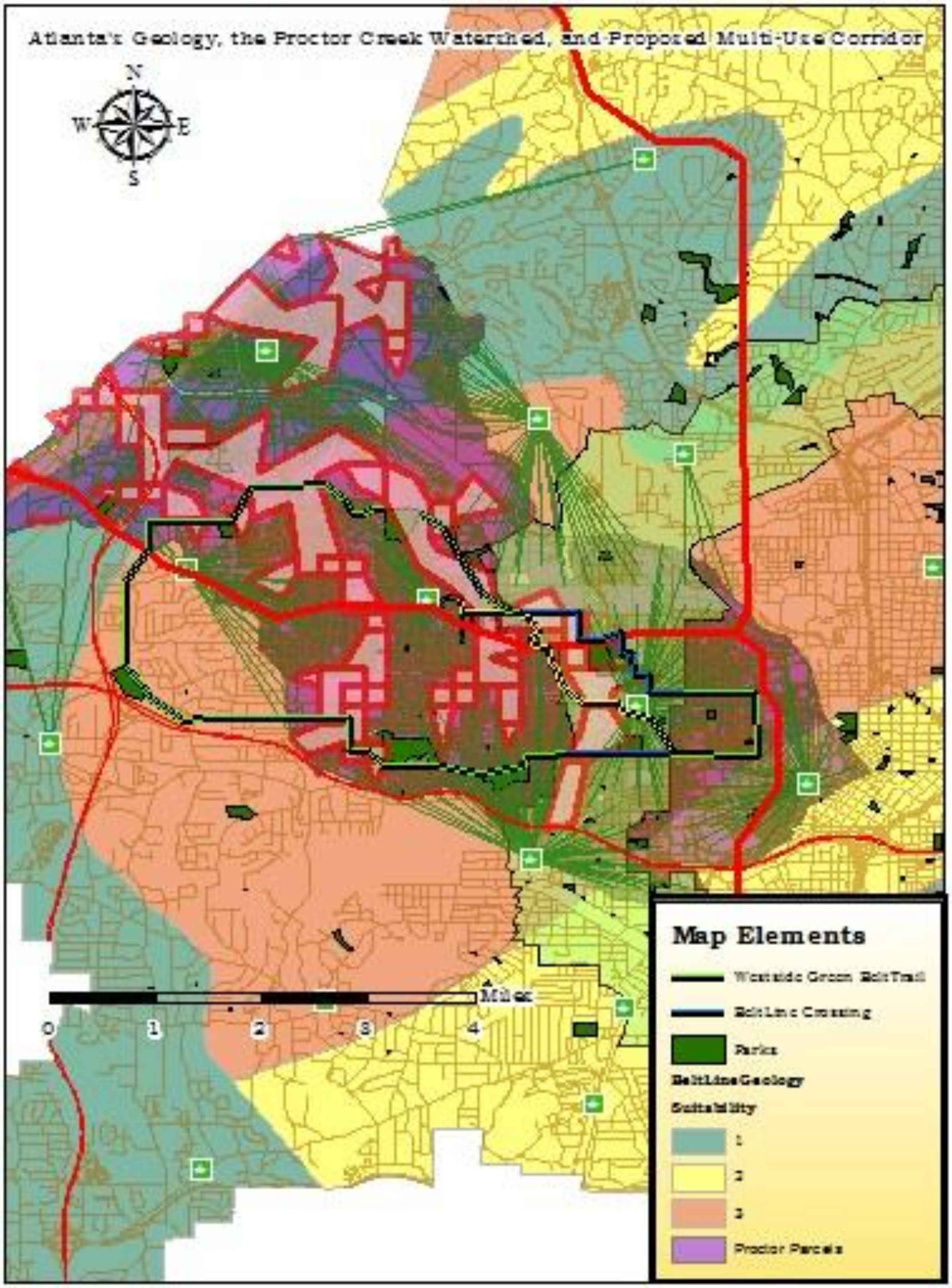

Figure 6.1: Final map.

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